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PROVISION OF THE CTF3 PHOTOINJECTOR LASER OSCILLATOR

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Abstract

We present the rationale for the choice of a commercial laser system as the front end of the CTF3 photoinjector laser chain. The required specifications are laid out and compared with the performance of the delivered system. The option of modifying the front end to allow phase-coding of the laser pulses is discussed.

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Introduction

The CTF3 photoinjector laser system has to deliver a high power train of ultraviolet pulses with a complex time-structure (see table 1). The pulse timing jitter has to be low and the amplitude jitter exceptionally low. The system must be reliable and straightforwardly maintainable. The latter requirement strongly favours existing commercial components unless there is an overriding technical or cost reason why these should not be used.

Parameter	**Unit**	**Value (at λ ~260 nm)**
Time between pulses	ns	0.667
Charge per pulse	nC	2.33
Charge stability	%	±0.1
Pulse width (FWHM)	ps	<10
Timing jitter from external 1.5GHz reference	ps	<±1
Pulse train duration	μs	1.54
Pulse train repetition rate	Hz	1-50

Table 1: Properties of the output beam from the CTF3 photoinjector laser

Design

The architecture of the whole photoinjector laser system is shown in fig 1. A cw modelocked oscillator provides a continuous train of ~10 ps pulses. Modelling suggests that the cw input to the pulsed amplifiers should have better than 0.2% rms pulse-to-pulse energy stability if 0.1% output stability is to be delivered.

The oscillator output is further amplified by solid-state, diode-pumped power amplifiers. The most effective way to generate the required energy per pulse in the ultraviolet is to amplify the pulses in the infrared and generate the 4th harmonic of the ~1 μm laser wavelength. Previous studies have shown that the best choice for the amplifying medium is Nd:YLF, working on its 1047 nm line. This then sets the choice of oscillator material. The initial system design was based on an Nd:YLF oscillator built in-house and delivering 30-50 W average power at 1.5 GHz repetition rate. Since the final pulse train mean power after the amplifiers in the IR needs to be 15 kW, the gain in the amplifiers would need to be 300-500. However high repetition rate (>1 GHz) oscillators using Nd:YLF have recently become commercially available, with the hardware necessary for sub-picosecond synchronisation to external RF. For the reasons described above, and because they also promise high levels of stability, the commercial components are attractive and the choice was made to investigate this option. However the average power of these systems is limited to the 1 W range. This requires some modifications to the amplifiers so that the final power can be reached with the lower energy seed pulses. This can be achieved with an additional cw preamplifier immediately after the oscillator.

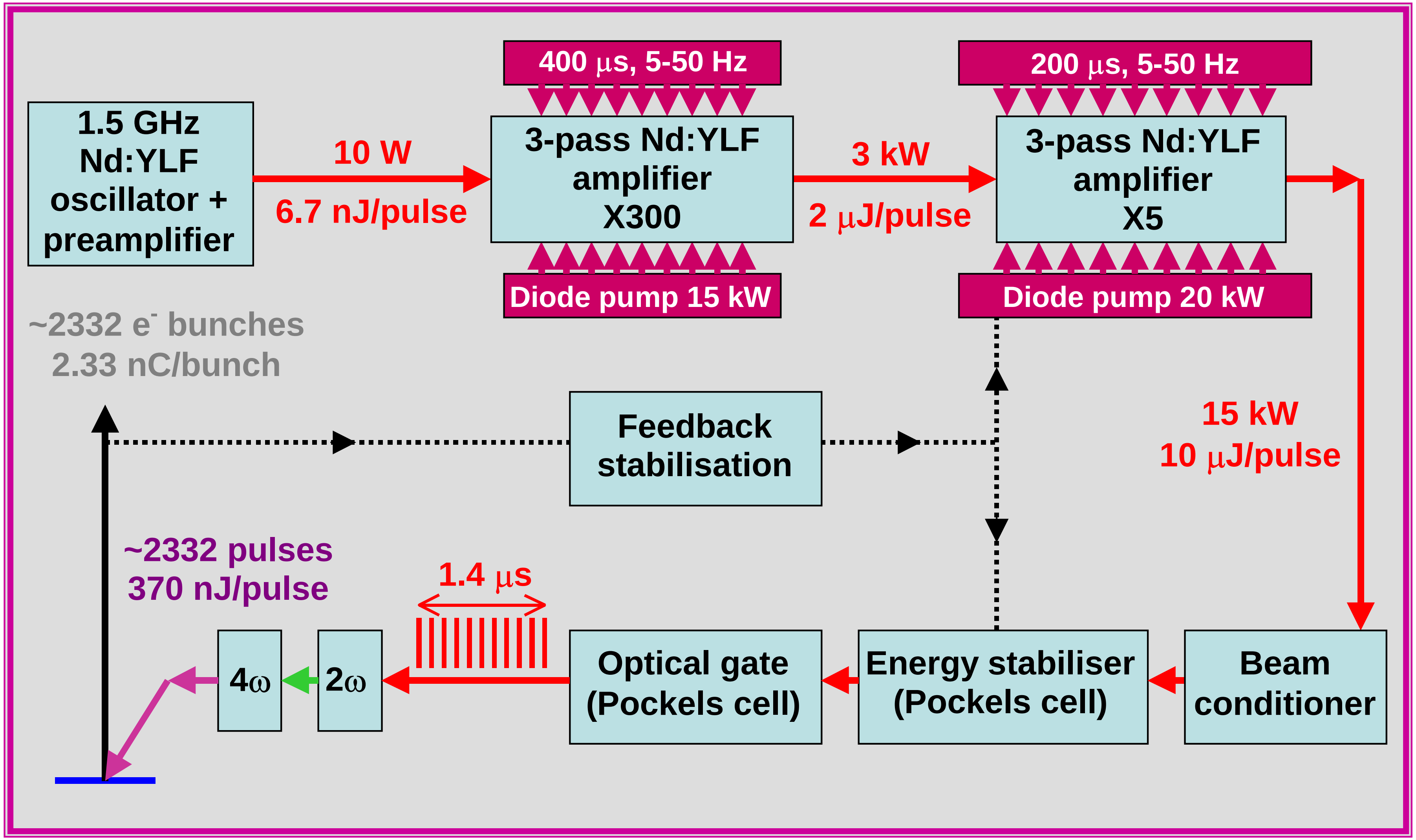

Figure 1: Proposed architecture for the CTF3 photo-injector laser system

Following the standard commercial route a call for tenders (see appendix 1) was sent out to 11 companies to supply an oscillator with the specifications shown in table 2. In addition a preamplifier was also specified to raise the average power of the cw pulse train to 10 W. It was expected that this approach would be cost-neutral and more time-effective than building in-house. The increased stability, the availability of long-term technical support and the reduced risk to the programme also favoured this choice.

Outcome

The chosen supplier of the oscillator and preamplifier was High Q Laser Production GmbH. The performance of their laser system during acceptance tests at the factory, at CERN and at RAL is also shown in table 2. The oscillator is a picoTRAIN unit, modelocked using semiconductor saturable absorber technology. The preamplifier is housed in a separate container which, like the oscillator, is designed for sealed operation to maximise reliability in industrial environments. A picture of the system is shown in fig 2.

Parameter	**Unit**	**Specification**	**Actual**
Laser gain medium		Nd:YLF	✓
Wavelength	nm	1047	✓
Mode of operation		cw modelocked	✓
Pulse repetition rate	MHz	1499.28	1499.28
Average oscillator power	W	0.2	0.32
Average preamplifier power	W	10	10.3
Pulse width (FWHM)	ps	<10	5.3
Timing jitter from 1.5GHz reference	ps	<±1	0.13 rms
Polarisation		Linear (1:500)	✓
Beam quality	M^2	TEM_{00}, $M^2<1.2$	$M^2=1.1$
Beam pointing stability	μrad/ºC	<±25	$\sigma_{ave}=25\mu rad$
Beam size stability		<5% rms size jitter	
Amplitude stability after 1 hr warm-up		<0.2% above 100 kHz <1% below 100 kHz	Noise<-60dBc above 100 Hz <0.56% over 13.5 hrs
Warranty period	years	1	✓
Repair and maintenance		Available for at least 5 years	✓

Table 2: Properties of the Nd:YLF oscillator and preamplifier

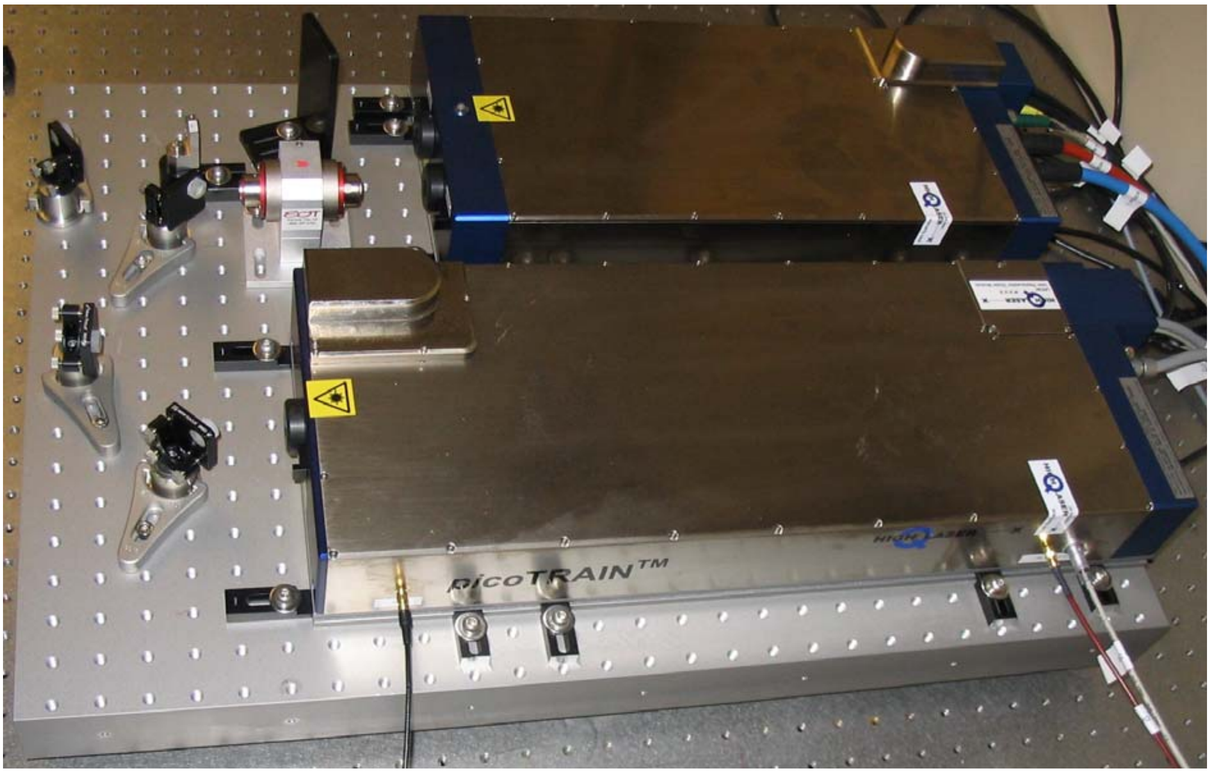

Figure 2: The picoTRAIN Nd:YLF oscillator (foreground), preamplifier and coupling optics

Notable among the laser's performance parameters is the very low timing jitter. The value shown in table 2 was measured at the High Q Laser factory. Repeat measurements at RAL produced even lower results (<100 fs) but it must be pointed out that the jitter is very sensitive to environmental conditions. In particular, the effects of acoustic noise and mechanical vibration can be very significant. The final value at CERN will need to be optimised in situ.

Postscript

Following the specification and delivery of the oscillator and preamplifier it became apparent that a further system requirement would need to be taken into account. The CTF3 accelerator includes components which selectively delay some of the electron bunches and then interleave them between others. This has the effect of increasing the electron bunch frequency from 1.5 GHz to 15 GHz with a corresponding reduction in the bunch train length. Operation of this system depends on the electron bunches being "phase coded" i.e. groups of 212 bunches need to be alternately delayed by 333 ps or not delayed. In principle this can be achieved most cleanly by optical coding of the laser pulses rather than electromagnetic coding of the electron bunches.

The original proposal was to code the laser pulses using a very fast Pockels cell and a split beam path. But the requirements for sub-nanosecond, multi-kV switching at ~7 MHz with very low amplitude noise proved extremely challenging. A lower risk approach is to use a high speed fibre modulator of the type developed for telecoms applications. This could switch quickly enough, but its limited power handling capability (<1 W) means that it would have to be placed between the laser oscillator and the preamplifier. Fortunately the High Q Laser system has the oscillator and preamplifier in two separate boxes, so adding a fibre-based system would involve minimal re-engineering.

The only other issue is that the fibre coding hardware is intrinsically lossy. Using connectorised components the overall power loss was estimated to be as high as 10 dB. An experiment was carried out to measure the effect of this loss on the performance of the oscillator/preamplifier system. With an ND 1.0 filter placed in the beam from the oscillator, the output of the preamplifier was measured. Despite the 10 dB reduction in the input, the output fell only to 6 W, just 2.2 dB below the specified 10 W. This reflects the strong saturation of the preamplifier stage. There should be sufficient capacity in the first power amplifier to recover this loss without adding any additional hardware to the system. However the effects on the output stability will need to be checked as the reduced preamplifier saturation may also lead to reduced suppression of any oscillator noise.

Acknowledgement

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Appendix 1 – Text of Call for Tenders

AB Department Project ***DO-21481/AB***

Technical Specification for the Supply of a 1.5 GHz mode-locked Nd:YLF oscillator at 1047 nm

Abstract

This technical description concerns the supply of a 1.5 GHz mode-locked Nd:YLF oscillator working at 1047 nm that will be the first stage of a chain for the generation of a highly stable (<0.1% rms) UV laser beam to be used for the production of electron beams through enlighten of a photocathode.

INTRODUCTION

Introduction to CERN

The European Organisation for Nuclear Research (CERN) is an intergovernmental organisation with 20 Member States*. It has its seat in Geneva but straddles the Swiss-French border. Its objective is to provide for collaboration among European States in the field of high energy particle physics research and to this end it designs, constructs and runs the necessary particle accelerators and the associated experimental areas.

At present more than 5000 physicists from research institutes world-wide use the CERN installations for their experiments.

Introduction to the PHIN Joint Research Activity (JRA) in the CARE Project

The CARE Project (Coordinated Accelerator Research in Europe) is an approved project of the 6th Framework Programme. PHIN ("Charge Production with Photo-Injectors") is one of the Joint Research Activities within CARE, and is devoted to the coordination of the efforts in progress inside several European laboratories to produce Electron beams by interaction of a laser beam with matter (either solid photocathodes or Plasmas). At CERN, a photoinjector using a laser beam illuminating the surface of a copper substrate coated with a film of CsTe and exposed to high level (85MV/m) 3 GHz Electric Field is under study in collaboration with the CCLRC Rutherford Appleton Laboratory (Chilton, England), and the Laboratoire de L'accélérateur Linéaire (Orsay, France).

Scope of the Price Enquiry

The aim of this Price Enquiry is to identify a company for the supply of a 1.5 GHz mode-locked Nd:YLF laser oscillator working at 1047 nm.

TECHNICAL DESCRIPTION OF THE SUPPLY

General

The oscillator, being the starting point of a more complex laser system, will have to provide a continuous train of mode-locked pulses with duration of less than 10 ps, and to ensure the stability of the energy from pulse to pulse to less than 0.2% rms in the greater than 100 kHz noise region and <1% rms stability in the less than 100kHz noise region. The oscillator will have to be capable of synchronisation to an external 1.5 GHz reference signal with a timing jitter less than +/-1 ps (peak to peak).

All the technical parameter required are listed in the following table:

* CERN Member States are: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, The Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom.

Laser gain medium	Nd:YLF
Wavelength	1047 nm
Type of operation	Continuous wave mode-locked
Repetition rate	1499.28 MHz
Average output power	> 0.2 W
Pulse width	< 10 ps FWHM
Timing jitter from an external 1.5 GHz RF source	<±1 ps peak to peak
Polarization	Linearly polarized (1:500)
Beam quality M^2	TEM_{00} M^2< 1.2
Beam pointing stability	±25 μrad/˚C
Beam size stability	5% rms size jitter
Amplitude stability after a 1 h warm-up	< 0.2 % rms above the 100 kHz noise region <1% rms stability below the 100kHz noise region
Warranty	1 year
Repair and maintenance	Available for at least 5 years

As an option, CERN would consider the possibility to purchase an oscillator with an amplifying stage for an output power < 10 Watts. All the other specified parameters for the beam should remain unchanged in this case. Please make an offer for this option if you are able to provide it.

It is required to provide a set of measurements on similar systems built by your company to prove that you are able to comply with the specifications above, in particular for what concerns the locking frequency, the timing jitter and the pulse to pulse energy stability.

CERN CONTACT PERSONS

Personal contact details removed.